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# Octave-spanning frequency comb generation in all-normal-dispersion silicon-rich silicon nitride waveguide

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**Abstract:** A frequency comb spanning from 1100 nm to 2200 nm is generated in an all-normal-dispersion silicon-rich silicon nitride waveguide. Phase noise measurements indicate that the supercontinuum generation retains the coherence. © 2020 The Author(s)

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## 1. Introduction.

Supercontinuum (SC) generation has been heavily studied in recent years. Since the emergence of microstructured fibers [1], SC sources have found applications in spectroscopy, optical coherence tomography and in f-2f stabilization of mode-locked lasers [2–5]. Lately, on-chip waveguides with core materials such as silicon nitride, silicon and lithium niobate [6–8], have been used to generate coherent octave-spanning SC. These waveguide structures favor a compact platform and facilitate octave-spanning broadening with low-energy pulses. The majority of the work in on-chip SC generation has been based on pumping waveguides in the anomalous dispersion regime, where soliton compression and fission, as well as dispersive-wave generation are the dominating spectral broadening mechanisms. Microstructured fibers offer another possibility that has been little explored in nanophotonic waveguides, namely operation in the normal dispersion regime over the whole available SC bandwidth (aka ANDi microstructure fibers). Here, the spectral broadening is mainly due to an interplay of self-phase modulation and chromatic dispersion, leading to optical wave breaking. ANDi fibers require higher pulse energy, but the spectrum can be notably smoother and more coherent [2], making it particularly well suited for long pump pulses [9]. To the best of our knowledge, this work demonstrates the first octave-spanning supercontinuum in an ANDi nanophotonic waveguide.

## 2. Results

The waveguide is based on the platform presented in [10]. A silicon-rich silicon nitride core of dimensions 2300 x 660 nm<sup>2</sup> (width x height) is surrounded by silica cladding. The geometry is carefully optimized to achieve a low all-normal group-velocity dispersion for the fundamental TE mode, see Fig. 1(a). The waveguide sustains 3 bounded TE modes. The waveguide has propagation losses of about 0.4dB/cm and is 4 cm long. Fabrication details and other parameters can be found in [10]. The waveguide is pumped by a commercial fs Er fiber laser frequency comb delivering a 45 fs pulse at 250 MHz repetition rate. The beam is free-space coupled into the waveguide, and the estimated on-chip average power is 32 mW. Based on these parameters, we run the simulation in Fig. 1(b), using the generalized nonlinear Schrödinger equation. The spectral evolution is dominated by self-phase modulation and optical wave breaking in the initial stage. The comparison between the simulation and the measured spectrum is presented in Fig. 1(c). The main spectral features are reproduced in the simulation when including the complex shape of the input pulse, and taking into account that 20% of the input pulse is coupled to a higher-order mode and remains unchanged during the propagation. Our simulations also predict that a flat spectrum with 5 dB spectral variation could be attained in the same waveguide structure assuming a perfectly Gaussian-shaped input pulse with identical pulse energy and duration coupled into the fundamental mode.

The preservation of the comb coherence upon SC generation is validated experimentally by assessing the quality of the repetition rate frequency. A portion of the SC is photodetected and the phase noise of the repetition rate is measured with the aid of an electrical spectrum analyzer. The SC is optically filtered to avoid photodiode saturation. By comparing the single-sideband phase noise of the 250 MHz signal before and after SC, see Fig. 1(d), we conclude that the SC introduces negligible noise.

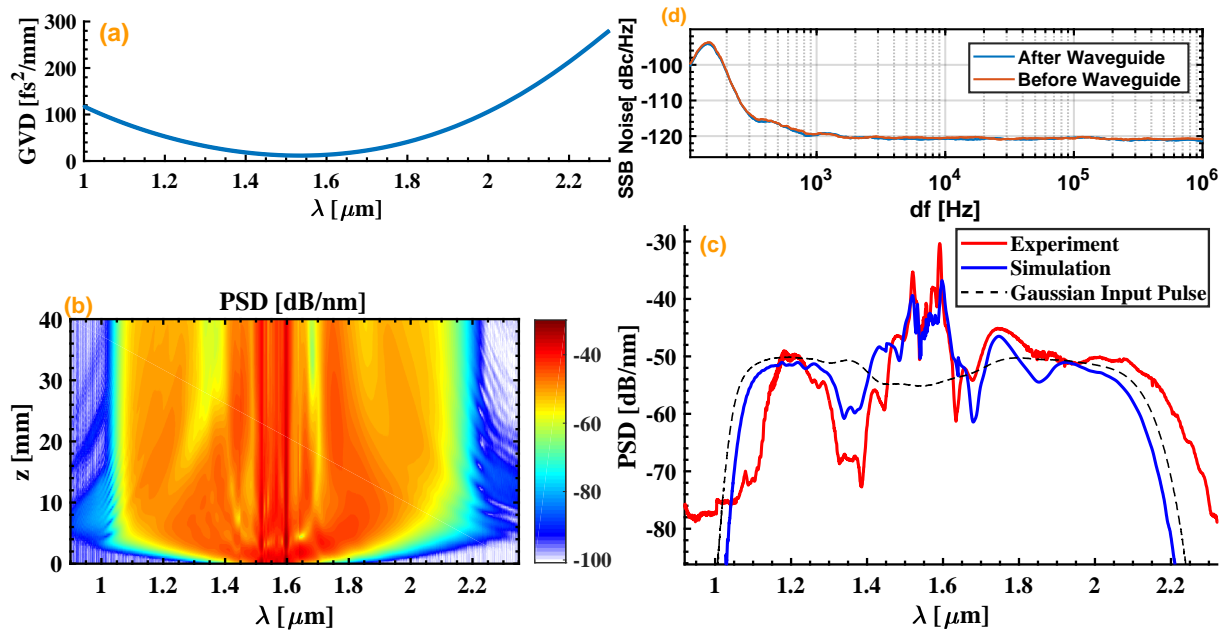


Fig. 1. (a) Simulated group velocity dispersion of 2300 by 660 nm<sup>2</sup> SiRN waveguide. (b) Simulated spectral evolution, when using pump laser spectrum as input. (c) Spectrum of experimental SC in red. Simulated spectrum with pump laser spectrum in blue. Simulated spectrum with perfect Gaussian pump in black. (d) Single-sided phase noise of the comb's repetition rate frequency and final SC when filtered around 1551nm.

### 3. Conclusion

To the extent of our knowledge, this is the first time an octave spanning SC frequency comb is generated in an on-chip platform using an ANDi waveguide. Phase noise measurements indicate that the generated SC retains coherence. With the aid of numerical simulations we show that by shaping the input pulse to a Gaussian, the spectral flatness of the comb could be improved.

### 4. Funding

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